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Temporal Variability of Daily Personal Magnetic Field Exposure Metrics in Pregnant Women

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Abstract

Recent epidemiology studies of power-frequency magnetic fields and reproductive health have characterized exposures using data collected from personal exposure monitors over a single day, possibly resulting in exposure misclassification due to temporal variability in daily personal magnetic field exposure metrics, but relevant data in adults are limited. We assessed the temporal variability of daily central tendency (time-weighted average, median) and peak (upper percentiles, maximum) personal magnetic field exposure metrics over seven consecutive days in 100 pregnant women. When exposure was modeled as a continuous variable, central tendency metrics had substantial reliability, whereas peak metrics had fair (maximum) to moderate (upper percentiles) reliability. The predictive ability of a single day metric to accurately classify participants into exposure categories based on a weeklong metric depended on the selected exposure threshold, with sensitivity decreasing with increasing exposure threshold. Consistent with the continuous measures analysis, sensitivity was higher for central tendency metrics than for peak metrics. If there is interest in peak metrics, more than one day of measurement is needed over the window of disease susceptibility to minimize measurement error, but one day may be sufficient for central tendency metrics.

Keywords

EMF; personal exposure; epidemiology

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLMENTAL INFORMATION

Supplemental information is available at *Journal of Exposure Science and Environmental Epidemiology*'s website.

INTRODUCTION

Over the past 30 years, a substantial amount of research has addressed whether or not exposure to power-frequency (i.e., 60-Hz in the U.S. and 50-Hz in other counties) magnetic fields is a risk factor for adverse reproductive health outcomes. The basis for this research priority arose from reports in 1979–1982 of miscarriage and birth defect clusters among video display terminal (VDT) operators in the U.S. and Canada.[1] From that point forward, much effort was invested to support epidemiology studies that examined the potential association between exposure to magnetic fields from VDTs and adverse pregnancy outcomes[2–12] as well as from exposure sources in and around the home, such as electric blankets, heated water beds, and power lines.[13–18] These studies produced conflicting results and many were characterized by study design limitations that possibly resulted in biased effect estimates, most notably from exposure misclassification due to the use of surrogate personal exposure measures, such as residential wire code classification and self-reported use of electric devices. The best effort to estimate personal exposure to magnetic fields quantitatively came from the use of spot measurements in residences and the workplace. However, the limitations with such an approach are that humans are not stationary and spot measurements do not incorporate differences in magnetic field exposures that result from moving between different environments. Because personal exposure monitors can capture variability in exposure over space and time, they provide a much more valid estimate of personal exposure.[19]

In 2002, the debate surrounding exposure to magnetic fields and adverse pregnancy outcomes was revived following the publication of two epidemiology studies conducted in pregnant women enrolled in the California Kaiser Permanente Medical Care Program.[20–21] At the time, these two studies were among the first of their kind to characterize personal magnetic field exposures using personal exposure monitors. While these two studies concluded that an elevated 24-hour personal maximum magnetic field exposure was associated with an increased risk of miscarriage (Li et al.[21] specifically pointed to a maximum threshold of 16.0 mG), there were a number of limitations that tempered their findings. The observed associations might be due to an unmeasured confounder[19,22] and, due to the likelihood of high day-to-day variability in personal magnetic field exposures, especially for the maximum, the exposure assessment strategy likely resulted in a high degree of exposure misclassification, which, if non-differential, would likely underestimate the association. The same approach where personal magnetic field exposures were characterized using a single day sample has been used in other more recent reproductive epidemiology studies as well conducted in pregnant women[23] and in men.[24] To date, studies of temporal variability of personal daily magnetic field exposure metrics in adults in the general population are limited both in number and scope[20,25] and, as a result, more comprehensive studies are needed. Studies reporting on distributions of daily personal magnetic field exposure metrics in adults that integrate exposures from magnetic field sources inside and outside the home are greatly needed as well.

The aim of our study was to evaluate the temporal variability of daily personal magnetic field exposure metrics among 100 pregnant women.[22] The Savitz et al.[22] study was originally designed to test the relationship between physical activity and personal magnetic field exposure. Here, we extend these data to examine temporal variability to help inform the characterization of personal magnetic field exposures and provide guidance on how to minimize measurement error in future reproductive health epidemiology studies.

MATERIAL AND METHODS

Study Participants

Participants in this study have been described previously.[22] Briefly, women were recruited using flyers posted in prenatal care clinics located Chapel Hill and Durham, North Carolina in 2003–2004. In order to participate in this study, participants were required to be 14–28 weeks' gestation, be ≥18 years old, have a singleton pregnancy, and agree to wear an accelerometer and a personal magnetic field exposure monitor for seven consecutive days. Those women agreeing to participate (N=100) provided informed consent and were compensated $75 at the end of their participation. The research protocol was approved by the School of Medicine Institutional Review Board at the University of North Carolina, Chapel Hill.

Measurement of Magnetic Field Exposure and Physical Activity

Participants were asked to wear at the hip level a small personal magnetic field exposure monitor called the EMDEX II (Enertech, Campbell, CA, USA), which is battery powered, moderately light weight (784 g), and about the size of a cellular phone (16.8 × 6.6 × 3.8 cm). The EMDEX II was calibrated to measure the magnetic field level in mG at 60 Hz with a frequency band ranging from 40–800 Hz. The EMDEX II measures the magnetic field level for the X-(horizontal), Y-(vertical), and Z-planes (lateral) and then calculates the resultant, which reflects the combined magnetic field levels across these three axes. The resultant, which we defined as the magnetic field level in this study, is calculated as follows: $R = (MF_x^2 + MF_y^2 + MF_z^2)^{0.5}$, where R is the resultant magnetic field level (mG), MF_x is the magnetic field level for the X-plane (mG), MF_y is the magnetic field level for the Y-plane (mG), and MF_z is the magnetic field level for the Z-plane (mG).

Participants were also asked to wear at the hip level an ActiGraph accelerometer (Model Number 7164, Pensacola, FL, USA), which is battery powered, weighs 45 g, and is small (5.1 × 3.8 × 1.5 cm). The ActiGraph is a uniaxial accelerometer that reports movement as "counts per epoch" (average counts/minute for this study) from the measured accelerations in the vertical plane. Average counts/minute represented an indication of total volume, with higher counts indicating higher overall physical activity.

Both monitors were programmed to record once per minute for seven consecutive days (i.e., 10,080 data points per monitor). Women were instructed to wear both monitors throughout the entire monitoring period (i.e., inside and outside the home), except at bedtime and when bathing, showering, or swimming, and to return the monitors by mail upon completion. These monitors, as well as similar monitors made by the same companies, have been used in many other studies conducted in adults.[20,21,23–29]

Measurement of Other Variables

Women were contacted at the end of the one week wearing period for a telephone interview to collect information on sociodemographics (including education, work status, children in the home), gestational age, any nausea during pregnancy, and general health.

Statistical Analysis

Statistical analyses were performed using SAS version 9.3 for Windows (SAS Institute, Cary, NC, USA). Periods in which the ActiGraph recorded ≥20 minutes of zero counts were defined as non-wear time for both monitors.[22,28,30] A sensitivity analysis was conducted without removing non-wear time (i.e., includes wear time and non-wear time) to explore if handling non-wear time modified the results (see Supplemental Information).

For each woman, daily central tendency (time-weighted average (TWA), median) and peak (90^{th}, 95^{th}, and 99^{th} percentiles, maximum) magnetic field exposure metrics and monitor wear durations were calculated. Distributions of these variables were calculated for the entire week and for weekdays only (i.e., Monday-Friday) and weekend days only (i.e., Saturday-Sunday) because we hypothesized there were differences in the values during these two timeframes due to differential mobility and environments experienced. To further explore this hypothesis statistically, differences in log-transformed personal magnetic field exposure metrics between weekdays and weekend days were tested using linear mixed models with a random subject effect to account for the correlation of measurements within an individual. Spearman's rank correlation coefficients and associated *p*-values were also calculated for weekly personal magnetic field exposure metrics to assess the relationships between all possible pairs of weekly exposure metrics.

To assess between- and within-person variability in daily magnetic field exposure metrics over one week, intraclass correlation coefficients (ICCs) were calculated using variance components from linear mixed models with a random subject effect only. Corresponding 95% confidence intervals (CIs) associated with each ICC were also calculated.[31] Savitz et al.[22] demonstrated in this cohort that increased physical activity is associated with a greater probability of experiencing elevated personal magnetic field exposures, which likely arise due to encountering a greater diversity in sources of magnetic fields. Similar findings were also reported by Mezei et al.[25] Therefore, it also follows that increased physical activity may result in increased variability in daily personal magnetic field exposure metrics over time. To explore differences in temporal reliability by physical activity, ICCs and their associated 95% CIs were calculated for tertiles (low, medium, and high) of average counts/minute. Differences in temporal reliability by maternal age (<30 years of age versus ≥30 years of age), education (high school or less versus some college versus college degree or higher), maternal race (black versus white or other), current work outside of the home (yes versus no), children ≤18 years of age at home (yes versus no), gestational age at measurement (13–20 weeks versus 21–25 weeks versus 26–29 weeks), any nausea during pregnancy (yes versus no), and general health (excellent/very good versus good/fair/poor) were also explored. The magnitude of the ICCs and Spearman's rank correlation coefficients was interpreted using the following criteria established by Landis and Koch[32]: slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00).

While the ICC is an indicator of the temporal reliability for continuous measures, it does not quantify how much exposure misclassification may occur if participants are categorized into different exposure groups (e.g., low vs. high exposure). For categorical exposure data analysis, sensitivity and specificity of a single day personal magnetic field exposure metric as a predictor of a high or low weeklong personal magnetic field exposure metric were evaluated by comparing the surrogate and observed exposure levels for agreement. For each participant, each daily exposure metric served as a surrogate for the weeklong exposure metric (i.e., observed) and was not included in the weeklong exposure metric calculation, which was derived using the data from the remaining six sampling days. For instance, if data from Monday was used in the derivation of the surrogate level, then only data from Tuesday-Sunday was used for calculating the observed level. This process was repeated for each day of the week for each participant, resulting in seven separate 2 × 2 contingency tables (i.e., one for each day of the week). All seven tables were then combined into a single table, where overall sensitivity and specificity were calculated. Sensitivity and specificity were calculated for the six personal magnetic field exposure metrics assessed in the ICC analysis for thresholds corresponding to the 50^{th}, 75^{th}, and 90^{th} percentiles of the daily personal magnetic field exposure metrics for the data set (as reported in Table 1). It should be noted, however, that the 70^{th} percentile (16.0 mG) was substituted for the 75^{th} percentile (18.7 mG) threshold in the sensitivity and specificity analyses for the maximum. Li et al.[21] reported that a daily maximum ≥16 mG is associated with an increased risk for miscarriage using magnetic field exposure data from a single day per subject and, as a result, we were interested in assessing the ability of this threshold to accurately classify individuals as highly exposed based on a single day magnetic field exposure measure.

RESULTS

Table 1 shows the distribution of the daily personal magnetic field exposure metrics for the entire cohort, who contributed 677 separate sampling days and wore the monitors for a median of 13.1 hours per day. The geometric mean (GM) magnetic field level was 0.8 mG for the TWA; 0.5 mG for the median; 1.5 mG for the 90^{th} percentile; 2.2 mG for the 95^{th} percentile; 4.3 mG for 99^{th} percentile; and 10.5 mG for the maximum. When stratifying on part of the week, monitors were worn slightly longer during weekdays than weekend days (median: 13.3 vs. 12.0 hours per day). Weekday daily personal magnetic field exposure metrics were also significantly higher ($p < 0.05$) than their respective weekend personal magnetic field exposure metrics, except for the maximum, which was not significantly different.

Spearman's rank correlation coefficients between weekly personal magnetic field exposure metrics are shown in Table 2. There were moderate to almost perfect positive correlations between all exposure metric pairs, except for the fair positive correlation between the median and maximum. Correlations for all exposure metric pairs were statistically significant ($p < 0.0001$).

ICCs, presented in Table 3, varied widely between daily personal magnetic field exposure metrics. The median (ICC: 0.66) and TWA (ICC: 0.64) were the most stable, exhibiting substantial reliability, followed by the 90th (ICC: 0.55), 95th (ICC: 0.49), and 99th (ICC: 0.43) percentiles, which demonstrated moderate reliability, and the maximum (ICC: 0.37), which showed fair reliability. These relationships were also qualitatively observable in Figure 1, which plots the day-to-day variation in the personal magnetic exposure metrics for a subset of 10 randomly selected participants. In particular, the peak magnetic field exposure metrics demonstrated greater intra-individual variability than the central tendency magnetic field exposure metrics for these women.

Figure 2 shows the ICCs for the daily personal magnetic field exposure metrics stratified on tertiles of average counts/minute. Similar to the unstratified analysis, ICCs for the central tendency measures were more stable over time than the peak measures. The daily personal magnetic field exposure metrics showed moderate to substantial reliability for women with low average counts/minute (ICC: 0.44–0.80), and fair to moderate reliability for women with medium average counts/minute (ICC: 0.25–0.48) and women with high average counts/minute (ICC: 0.35–0.60). Differences in ICCs were also observed by maternal age (ICCs were more stable in women <30 years of age (N=41) compared to women ≥ 30 years of age (N=59)) and maternal race (ICCs were more stable in black women (N=22) compared to white or other women (N=78)) (data not shown). However, there was no consistent difference in ICCs by education, current work outside of the home, children ≤18 years of age at home, gestational age at measurement, any nausea during pregnancy, or general health (data not shown).

Table 4 shows the predictive ability of a single day personal magnetic field exposure metric to classify a participant into high or low categories of exposure based on a weeklong personal magnetic field exposure metric. The proportion of participants that had an elevated weekly exposure and would be identified as such using a single day personal magnetic field exposure metric at any time during the week (i.e., sensitivity) ranged from 0.51–0.76 for the TWA; 0.58–0.83 for the median; 0.62–0.68 for the 90th percentile; 0.43–0.67 for the 95th percentile; 0.26–0.62 for the 99th percentile; and 0.20–0.54 for the maximum. Except for the median, sensitivities decreased with increasing exposure thresholds. The proportion of women with a reduced weekly exposure that would be classified as such using a single day personal magnetic field exposure metric at any time during the week (i.e., specificity) ranged from 0.75–0.95 for the TWA; 0.81–0.94 for the median; 0.73–0.90 for the 90th percentile; 0.75–0.94 for the 95th percentile; 0.72–0.92 for the 99th percentile; and 0.83–0.95 for the maximum. The specificities increased with increasing exposure thresholds and, on average, the magnitude of the specificities was greater than the respective sensitivities.

All analyses presented were repeated without removing non-wear time and generated comparable results (see Supplemental Information).

DISCUSSION

In this study, we evaluated the temporal variability of continuous and categorical daily personal magnetic field exposure metrics over seven consecutive days in a cohort 100 pregnant women from North Carolina. The daily median exhibited the greatest stability, followed by the TWA, 90th percentile, 95th percentile, 99th percentile, and maximum. When modeling exposure as a continuous variable, our results suggest that it may be possible to characterize personal magnetic field exposures in reproductive health epidemiology studies with central tendency exposure metrics derived from a single measurement day. On the other hand, use of a single day peak exposure metric, especially the maximum, will likely result in appreciable exposure misclassification. The same was concluded for categorical exposure metrics, but the temporal variability appears to be dictated by the selected exposure threshold, with decreasing stability over time with increasing exposure threshold.

Comparing the present data with those measured over a single 24-hour period in a representative subset of U.S. women and men ≥18 to <65 years old (N=716),[33] the GM TWA in this study was slightly lower with a value of 0.8 mG versus 1.0 mG for the U.S. survey. This study also had a slightly lower GM TWA (0.8 versus 1.2 mG), median (0.5 versus 0.8 mG), and 90th (1.5 versus 2.1 mG), 95th (2.2 versus 2.9 mG), and 99th (4.3 versus 5.8 mG) percentiles, and a much lower GM maximum (10.5 versus 29.9 mG) compared with the supplemental analyses of the single 24-hour personal magnetic field exposure levels measured in the California Kaiser Spontaneous Abortion Study (N=960).[21,34] Mezei et al.[25] demonstrated that longer sampling intervals tended to result in lower exposure metric values, particularly for the maximum, which may explain the differences in the magnitudes between the metrics in our study (sampling interval: 60 seconds) compared to the U.S. survey (sampling interval: 0.5 seconds) and the Kaiser Study (sampling interval: 10 seconds).

We are currently unaware of any other studies that have compared weekday and weekend day personal magnetic field exposure metrics. Our results suggest that there may be differences in the intensity, frequency, and/or duration of personal magnetic field exposures during these two time periods, with exposures being slightly higher during weekdays than weekend days. These differences are potentially explained by differences in mobility patterns throughout the week. For example, the environments experienced and/or activities performed during the week may be different than those during the weekend and, as a result, interaction with magnetic field sources may be different as well. However, because the women did not fill out a diary with information on their locations and activities during the measurement period, exploration of this hypothesis was not possible.

Given that the biologically-relevant personal magnetic field exposure metric in miscarriage epidemiology studies remains a subject of debate, there are numerous possibilities that could be used to define exposure. Previous miscarriage epidemiology studies[20,21] have focused on the TWA and maximum among others. In our analysis, the TWA was well correlated with the median and 90th, 95th, and 99th percentiles and, as such, the TWA may be a suitable surrogate for these other exposure metrics and vice versa. However, the TWA was independent of the maximum as expected. Other studies in adults have also reported that the TWA is not well correlated with maximum.[20,33]

To date, two other studies have assessed intra-individual temporal variability in personal magnetic field exposure metrics in adults in the general population.[20,25] Lee et al.[20]

measured 24-hour personal magnetic field exposure levels at 12 and 30 weeks of gestation in 219 women from the California Kaiser Permanente Medical Care Program. Pearson correlation coefficients for the TWA and maximum between the two time points were 0.64 and 0.09, respectively. Mezei et al.[25] re-analyzed data from the Electric Power Research Institute Long-Term Wire Code Study,[35] where personal magnetic field exposure levels were measured in men and women in 218 U.S. households on up to four home visits (mean and standard deviation duration per visit were 33.5 and 13.0 hours, respectively) over a 20 month period. Spearman correlation coefficients between the first and last visits for the maximum and 99th and 95th percentiles were 0.31, 0.68, and 0.78, respectively. Correlations between pairs of visits ranged from 0.27 (>15 months between visits) to 0.35 (<6 months between visits) for the maximum; 0.62–0.65 for the 99th percentile; 0.75–0.84 for the 95th percentile; 0.80–0.87 for the median; and 0.70–0.82 for the TWA.

In comparison to earlier studies, our ICC analysis was more robust because we included personal magnetic field exposure data for up to seven consecutive days per participant, as opposed to two measurement periods per participant ranging from about 1–2 days in duration separated by several weeks. Our derived personal magnetic field exposure metrics were based on data collected inside and outside the home, which provides a more valid estimate of exposure than exposure metrics based on data collected inside the home only as performed in Mezei et al.[25] Activities that are performed outside the home, such as work and travel, are important contributors to daily magnetic field exposure,[33] and failure to include associated exposures in derived exposure metrics may introduce bias. Nevertheless, the results from our analysis are consistent with these two studies and suggest that, as continuous variables, daily central tendency metrics associated with personal magnetic field exposures exhibit greater temporal stability compared with daily peak metrics. Our findings also indicate that it may be possible to characterize personal magnetic field exposures in epidemiology studies with central tendency exposure metrics derived from a single measurement day. However, epidemiology studies that characterize personal magnetic field exposure with a continuous peak exposure metric, especially the maximum, based on a single measurement day will likely result in a large degree of exposure misclassification. For example, in order for the 90th and 95th percentiles to be as stable as the median, it would require two days of sampling versus one day of sampling. Whereas, the 99th percentile and maximum would require three and four days of sampling, respectively, versus one day of sampling to be as stable as the median (data not shown).[36]

We also demonstrated that higher average counts/minute (indicating higher overall physical activity) was associated with greater within-subject variability in the daily personal magnetic field exposures, which could be explained by the fact that more active individuals have a greater probability of encountering sources of magnetic fields with a larger range in intensities on any given day than less active individuals. Our findings support other analyses showing that physical activity is associated with personal magnetic field exposures in women.[22,25] Our findings additionally suggest that maternal race and maternal age may be associated with personal magnetic field exposure in women. These differences may also be related to differences in mobility patterns and consistency of exposure sources between groups over time.

We are only aware of one study in the literature that has evaluated intra-individual temporal variability in categorical personal magnetic field exposure metrics in adults in the general population.[20] In that study, Lee et al.[20] also used the 24-hour personal magnetic field exposure levels measured at 12 and 30 weeks of gestation to calculate the proportion of participants that had an elevated or reduced TWA or maximum exposure at 30 weeks of gestation (threshold defined as the median value across all data sets at 30 weeks of gestation for that metric) and would be identified as such using the exposure at 12 weeks of gestation. The authors reported that the sensitivities for the 24-hour TWA and maximum were 0.77 and 0.60, respectively, and the corresponding specificities were 0.96 and 0.51, respectively.

While these findings were comparable to the sensitivity for the TWA and maximum in our study when using the median as the threshold, the corresponding specificity in our study was much lower for the TWA and much higher for the maximum. Contrary to Lee et al.,[20] we calculated the sensitivities and specificities for the TWA and maximum, as well as for other central tendency and peak personal magnetic field exposure metrics, at several different exposure thresholds. In particular, using the 16.0 mG threshold for the maximum reported by Li et al.[21] may lead to substantial exposure misclassification. On examining this threshold further, we found that the percentage of women with at least one daily maximum ≥16 mG increased with each additional sampling day over the course of the week (31.8–78.8%) (data not shown), which suggests that most women at some point will likely experience a personal magnetic field exposure ≥16.0 mG and, as a result, the validity of this exposure threshold is questionable.

Our results also demonstrate that sensitivity decreases with increasing exposure threshold, whereas specificity increases with increasing exposure threshold, which suggests that selection of the exposure threshold may dictate how stable the exposure metric is over time. These trends are expected due to the distribution of daily personal magnetic field exposure metrics and where the threshold falls in the distribution. The closer the threshold is to the upper tail of the distribution, the lesser the number of daily exposures above that threshold. Thus, in the event that a participant has a weeklong exposure above the threshold, she is more likely to have an exposure on any given day of the week below rather than above that threshold as the threshold moves closer to the upper tail of the distribution, leading to a lesser number that are correctly classified as highly exposed (i.e., sensitivity). On the other hand, as the threshold increases, the greater the number of daily exposures below that threshold and, as a result, a greater probability for having both a daily and weeklong exposure below the threshold, resulting in a greater number correctly classified as underexposed (i.e., specificity).

Unique strengths of our study were the robustness of the data set, which contained thousands of repeated measurements per subject, and the variety of personal magnetic field exposure metrics assessed as both continuous and categorical variables. One limitation of our study was that the data were concentrated within a relatively short time period (one week), and it is uncertain how our findings relate to longer “at risk” time periods that are commonly examined in reproductive epidemiology studies (e.g., miscarriage), which may be on the order of several months. However, requesting participants to wear the monitors for longer than seven consecutive days would increase participant burden and likely result in lower participation rates. Nevertheless, the results of this study are consistent with the small number of studies that have examined the temporal variability of personal magnetic field exposure metrics in adults,[20,25] may be applicable to epidemiology studies of health outcomes that occur during short windows of time (e.g., unsuccessful fertilization, implantation failure, and very early miscarriage), and may serve as lower-bound estimates of temporal variability over longer periods of time. In addition, while the ActiGraph provides an objective measure of physical activity, the algorithm[22,28,30] that was used to define non-wear time from the accelerometer was conservative and may have misclassified some minutes, particularly time in sedentary behavior. A final limitation of the current study relates to the uncertainty in our ability to generalize the results to other populations, especially children whose interaction with magnetic field sources may differ from adults.

In conclusion, to our knowledge, this is the most complete analysis of temporal variability of daily personal magnetic field exposure metrics in adults in the peer-reviewed literature. We demonstrated that characterizing personal magnetic field exposures in pregnant women with a single day sample may lead to substantial exposure misclassification for peak magnetic field exposure metrics, especially the maximum, compared with central tendency magnetic field exposure metrics when modeled as continuous variables. The same relationship was observed when exposure levels were categorized, though the temporal variability of the exposure metric depended on the criteria used for categorization. If there is interest in peak personal magnetic field exposure metrics (e.g., upper percentiles, maximum), more than one day of measurement is needed over the window of disease susceptibility to minimize measurement error. However, this approach will need to be balanced by the realistic financial and participant burden constraints that are often associated with large-scale studies. At the very least, a nested temporal variability study should be conducted to gauge the extent of any measurement error in the parent study.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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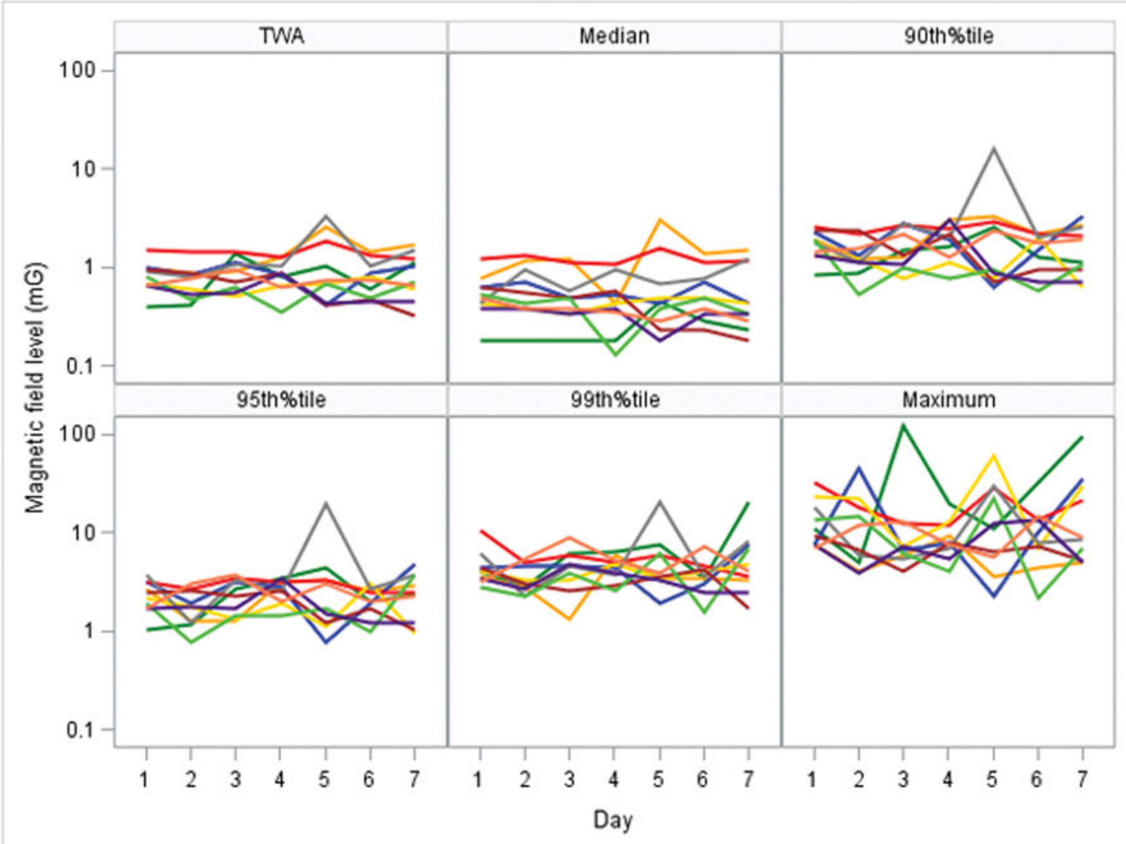

Figure 1.

Day-to-day variation in daily personal magnetic field exposure metrics over one week for a subset of the same 10 participants (wear time data only). Each color represents a different participant.

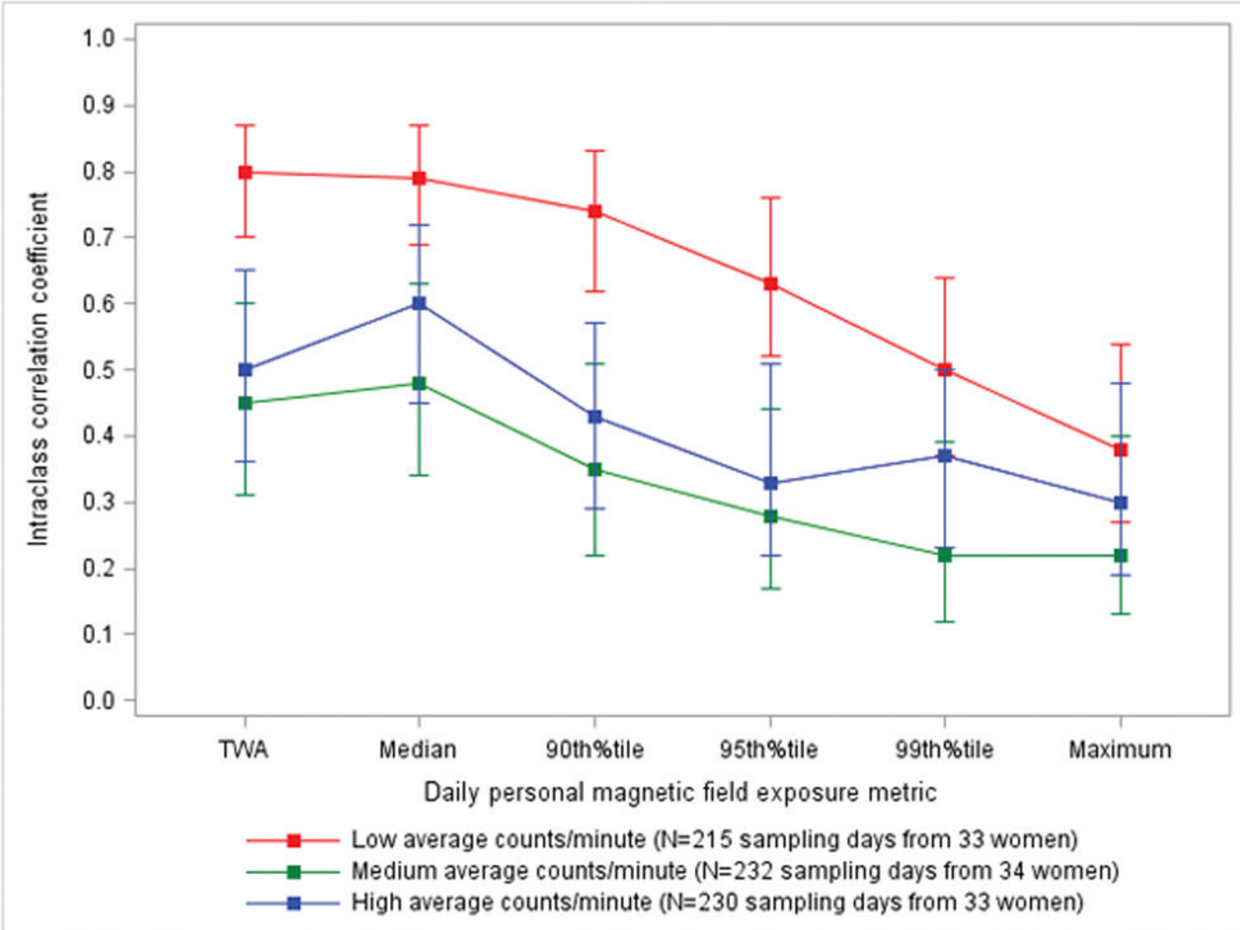

Figure 2.

Intraclass correlation coefficients (ICCs) and 95% confidence intervals (95% CIs) for log-transformed daily personal magnetic field exposure metrics over one week by tertiles of average counts/minute (wear time data only). The boxes represent the ICCs and the horizontal lines represent the lower and upper bounds of the 95% CIs.

Table 1

Distribution of daily personal magnetic field exposure metrics (mG) and daily magnetic field exposure monitor and accelerometer wear time (hours) by part of the week (wear time data only)

	Daily wear time			Percentiles					
Part of the week	**Median (IQR)**	**Metric**	**GM**	**10th**	**25th**	**50th**	**75th**	**90th**	**Max.**
Entire week (Mon.–Sun.)[1]	13.1 (11.4–14.4)	TWA	0.8	0.3	0.6	0.8	1.3	1.9	26.8
		Median	0.5	0.2	0.3	0.5	0.9	1.5	35.6
		90th%tile	1.5	0.5	1.0	1.6	2.5	3.9	37.1
		95th%tile	2.2	0.8	1.4	2.3	3.4	5.1	74.1
		99th%tile	4.3	1.5	3.0	4.4	6.8	11.3	133
		Maximum	10.5	3.2	6.3	10.1	18.7	37.4	1209
Weekdays (Mon.–Fri.)[2]	13.3 (11.8–14.7)	TWA[3]	0.9	0.4	0.6	0.8	1.3	2.0	11.6
		Median[3]	0.5	0.2	0.3	0.5	0.9	1.5	18.4
		90th%tile[3]	1.6	0.6	1.0	1.6	2.6	4.0	30.5
		95th%tile[3]	2.3	0.9	1.5	2.4	3.5	5.6	74.1
		99th%tile[3]	4.4	1.6	3.2	4.5	6.9	11.5	133
		Maximum	10.8	3.5	6.8	10.2	18.8	35.1	1209
Weekend days (Sat.–Sun.)[4]	12.0 (10.5–13.5)	TWA	0.8	0.3	0.5	0.7	1.2	1.9	26.8
		Median	0.4	0.1	0.3	0.4	0.9	1.5	35.6
		90th%tile	1.4	0.5	0.9	1.4	2.4	3.5	37.1
		95th%tile	2.0	0.7	1.3	2.0	3.1	4.7	37.4
		99th%tile	4.0	1.2	2.8	4.4	5.9	10.6	119
		Maximum	9.8	2.3	5.5	9.9	18.0	40.4	238

GM, geometric mean; IQR, interquartile range; max., maximum; TWA, time-weighted average;

[1] 677 sampling days from 100 women;

[2] 488 sampling days from 100 women;

[3] test for fixed effect for weekdays only (vs. weekend days only) using log-transformed personal magnetic field exposure metrics in linear mixed models with random subject effects, $p < 0.05$;

[4] 189 sampling days from 99 women.

Table 2

Spearman's rank correlation coefficients (r_s) among weekly personal magnetic field exposure metrics (wear time data only)

	Metric					
Metric	**TWA**	**Median**	**90th%tile**	**95th%tile**	**99th%tile**	**Maximum**
TWA						
r_s[1]	1.00	0.86	0.90	0.87	0.76	0.53
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Median						
r_s[1]		1.00	0.72	0.62	0.48	0.30
P			<0.0001	<0.0001	<0.0001	<0.0001
90th%tile						
r_s[1]			1.00	0.92	0.71	0.47
P				<0.0001	<0.0001	<0.0001
95th%tile						
r_s[1]				1.00	0.83	0.54
P					<0.0001	<0.0001
99th%tile						
r_s[1]					1.00	0.72
P						<0.0001
Maximum						
r_s[1]						1.00
P						

TWA, time-weighted average;

[1] 677 sampling days from 100 women.

Table 3

Intraclass correlation coefficients (ICCs) and 95% confidence intervals (95% CIs) for log-transformed daily personal magnetic field exposure metrics over one week (wear time data only)

Metric	ICC[1]	95% CI
TWA	0.64	0.56, 0.71
Median	0.66	0.58, 0.73
90th%tile	0.55	0.46, 0.63
95th%tile	0.49	0.40, 0.57
99th%tile	0.43	0.35, 0.52
Maximum	0.37	0.28, 0.45

TWA, time-weighted average;

[1] 677 sampling days from 100 women.

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Table 4

Sensitivity and specificity for predicting participants with a weekly personal magnetic field exposure metric exceeding or not exceeding thresholds (mG) using a single daily personal magnetic field exposure metric surrogate (wear time data only)

Metric	Threshold[1]	Sensitivity[2,3]	Specificity[2,3]
TWA	≥0.8	0.76	0.75
	≥1.3	0.69	0.92
	≥1.9	0.51	0.95
Median	≥0.5	0.80	0.81
	≥0.9	0.83	0.92
	≥1.5	0.58	0.94
90th%tile	≥1.6	0.68	0.73
	≥2.5	0.64	0.88
	≥3.9	0.62	0.95
95th%tile	≥2.3	0.67	0.75
	≥3.4	0.57	0.85
	≥5.1	0.43	0.94
99th%tile	≥4.4	0.62	0.72
	≥6.8	0.41	0.82
	≥11.3	0.26	0.92
Maximum	≥10.1	0.54	0.83
	≥16.0[4]	0.36	0.88
	≥37.4	0.20	0.95

TWA, time-weighted average;

[1]thresholds defined as the 50th, 75th, and 90th percentiles of the daily personal magnetic field exposure metrics;

[2]each daily personal magnetic field exposure metric surrogate was not included in the calculation of the weekly personal magnetic field exposure metric;

[3]677 sampling days from 100 women;

[4]reported by Li et al. (2002) as the threshold above which there is an increased risk of miscarriage, 16.0 mG is about the 70th percentile of the daily personal magnetic field exposure maximums.